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(54) **VOLTAGE REGULATING APPARATUS WITH ENHANCEMENT FUNCTIONS FOR TRANSIENT RESPONSE**

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G05F 1/565 (2006.01)
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(52) **U.S. Cl.**
CPC ***G05F 1/10*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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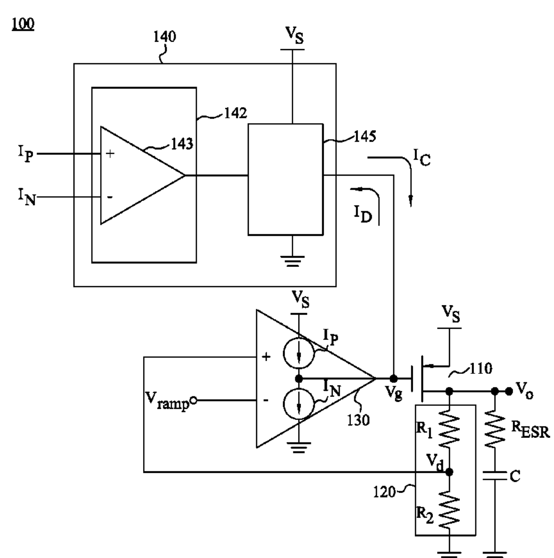
(57) **ABSTRACT**

A voltage regulating apparatus is disclosed. The voltage regulating apparatus includes: a power transistor having a control terminal, a first terminal for receiving a power supply, and a second terminal for providing an output voltage; a feedback circuit coupled to the second terminal, configured for providing a feedback voltage according to the output voltage; an amplifier having a source current unit and a sink current unit, configured for driving the power transistor through the control terminal by use of the source and sink current units according to a reference voltage and the feedback voltage; and a transient enhancement unit configured for monitoring the source and sink current units, and regulating a voltage at the control terminal according to the monitored result.

12 Claims, 3 Drawing Sheets



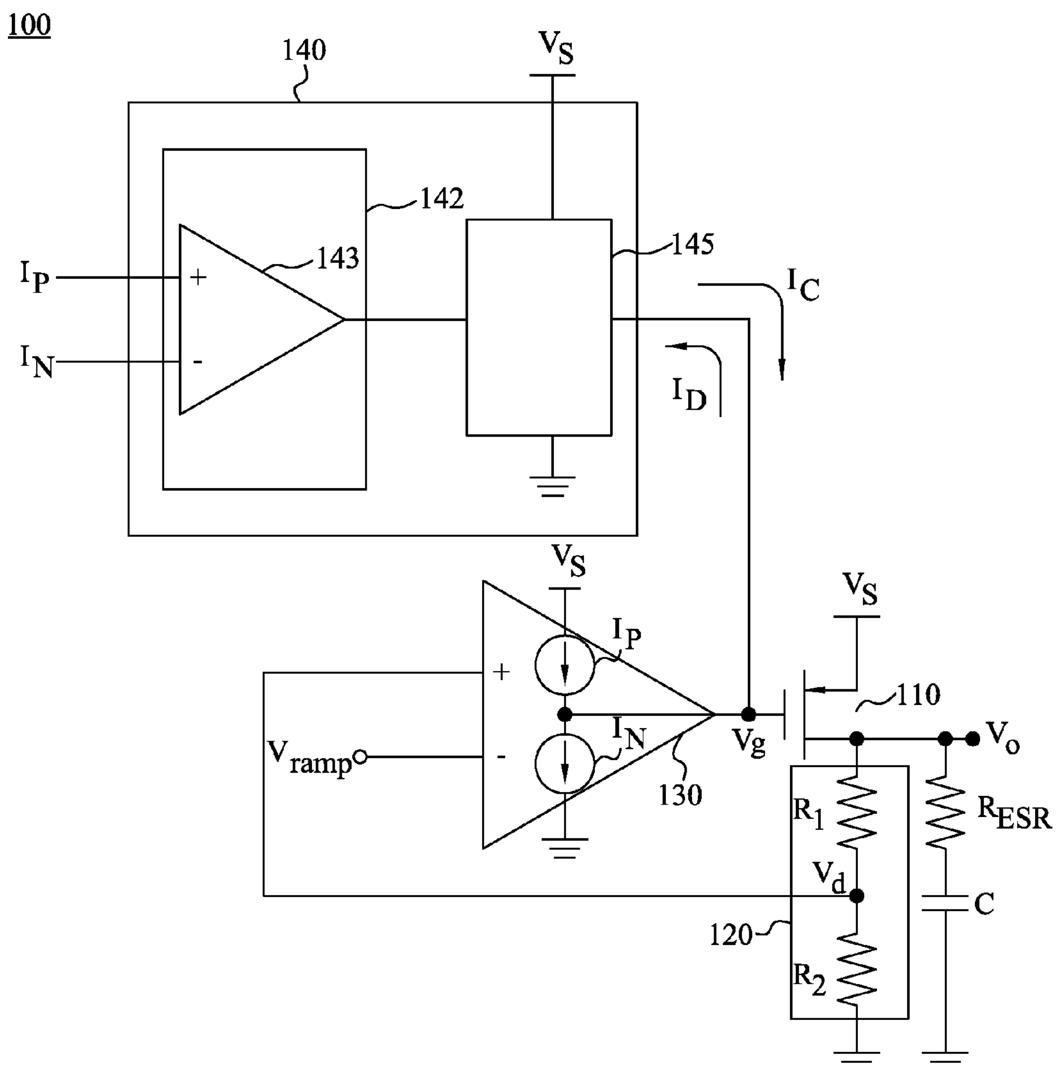

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FIG. 1

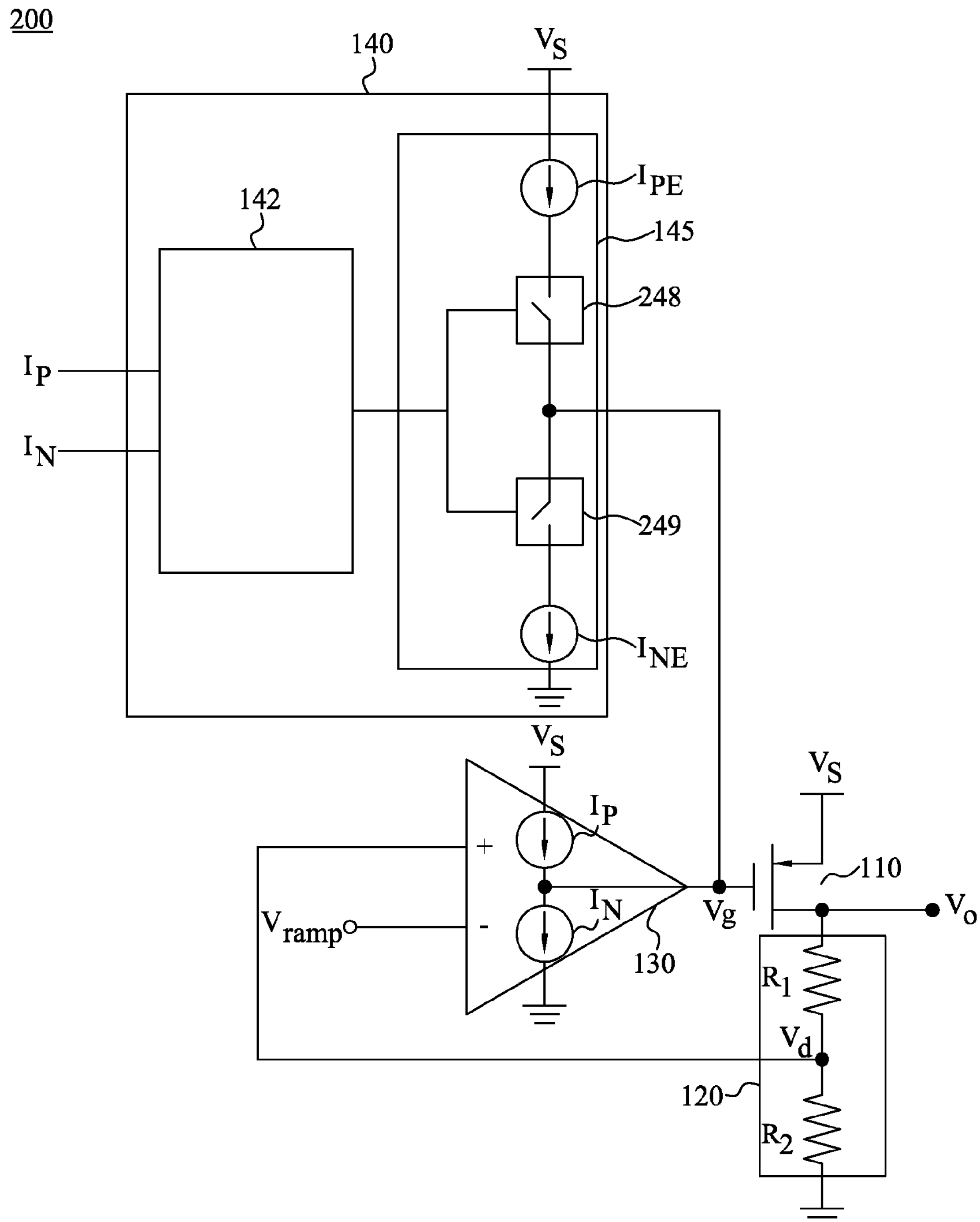
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FIG. 2

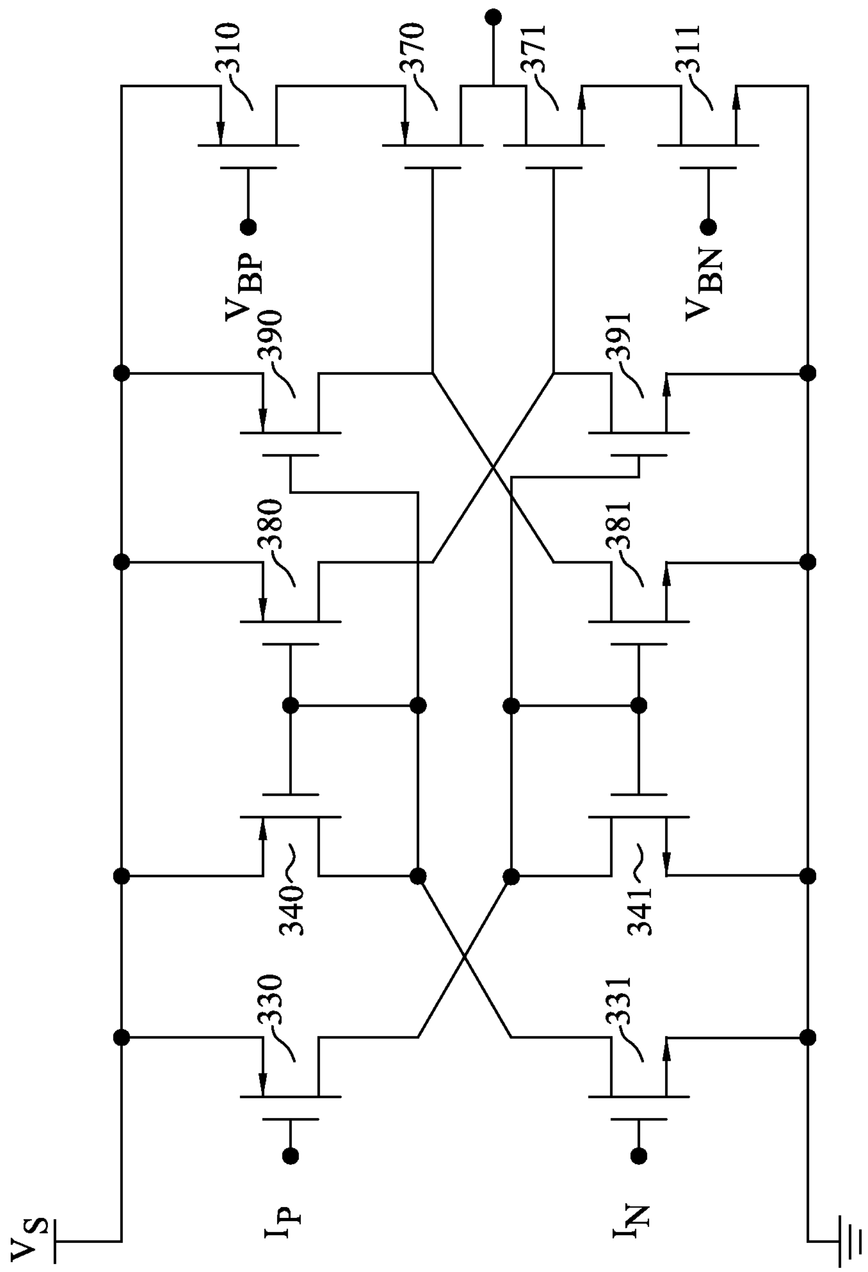

FIG. 3

VOLTAGE REGULATING APPARATUS WITH ENHANCEMENT FUNCTIONS FOR TRANSIENT RESPONSE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of Taiwan application Serial No. 101115139, filed Apr. 27, 2012, the disclosure of which is incorporated by reference herein in its entirety.

TECHNICAL FIELD

The present disclosure relates to a voltage regulator, and more particularly, to a voltage regulating apparatus with enhancement functions for the transient response.

TECHNICAL BACKGROUND

A voltage regulator is a device designed to provide a specific constant voltage level over a range of load conditions. It is widely used in portable electronic devices, such as a cellular phone, a laptop computer, and a personal digital assistant (PDA). Due to the requirements of low power consumption and high reliability for portable electronic devices, remarkable endeavors have been involved in the design and fabrication of voltage regulators.

In the case that the load condition of the voltage regulator is switched from one to the other, the load current outputted by the voltage regulator may change suddenly. The fast change may produce transient electrical spikes or pulses at the output voltage, causing an unfavorable effect to most electronic devices of digital circuit. Therefore, it is in need to develop a new voltage regulating apparatus with enhancement functions for the transient load change. The enhancement functions can speed up the response for the load change and, concurrently, refrain the quiescent-state current from growing up, so that performance of the voltage regulators can be improved and battery duration of the portable devices can be extended, too.

TECHNICAL SUMMARY

Therefore, one of the objects of the present disclosure is to provide a voltage regulating apparatus with enhancement functions for the transient response, which can speed up the response for the load change and refrain the quiescent-state current from growing up.

According to one aspect of the present disclosure, one embodiment provides a voltage regulating apparatus, which includes: a power transistor having a control terminal, a first terminal for receiving a power supply, and a second terminal for providing an output voltage; a feedback circuit coupled to the second terminal, configured for providing a feedback voltage according to the output voltage; an amplifier having a source current unit and a sink current unit, configured for driving the power transistor through the control terminal by use of the source and sink current units according to a reference voltage and the feedback voltage; and a transient enhancement unit configured for monitoring the source and sink current units, and regulating a voltage at the control terminal according to the monitored result.

According to another aspect of the present disclosure, another embodiment provides a voltage regulating apparatus which includes: a power transistor having a control terminal, a first terminal for receiving a power supply, and a second terminal for providing an output voltage; a feedback circuit configured for providing a feedback voltage according to the output voltage; an amplifier having a source current unit and a sink current unit, configured for receiving a reference voltage and the feedback voltage, and driving the power transistor through the control terminal by use of the source and sink current units; and a transient enhancement unit configured for monitoring the source and sink current units, and charging or discharging the control terminal according to the monitored result.

Further scope of applicability of the present application will become more apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating exemplary embodiments of the disclosure, are given by way of illustration only, since various changes and modifications within the spirit and scope of the disclosure will become apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will become more fully understood from the detailed description given herein below and the accompanying drawings are given by way of illustration only, and thus are not limitative of the present disclosure and wherein:

FIG. **1** schematically shows a circuit diagram of a voltage regulating apparatus according to an embodiment of the present disclosure.

FIG. **2** schematically shows a circuit diagram of a voltage regulating apparatus according to another embodiment of the present disclosure.

FIG. **3** schematically shows a circuit configuration of the transient enhancement unit as an example of the embodiment.

DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

For further understanding and recognizing the fulfilled functions and structural characteristics of the disclosure, several exemplary embodiments cooperating with detailed description are presented as the following. Reference will now be made in detail to the preferred embodiments, examples of which are illustrated in the accompanying drawings. In the following description of the embodiments, it is to be understood that the terms "first", "second" and "third" are used to describe various elements, these elements should not be limited by the term. Also, unless otherwise defined, all terms are intended to have the same meaning as commonly understood by one of ordinary skill in the art.

FIG. **1** schematically shows a circuit diagram of a voltage regulating apparatus **100** according to an embodiment of the present disclosure, which can be used to describe the circuit operations of a voltage regulating apparatus with enhancement functions for the transient response. A voltage regulating apparatus can be referred to as "voltage regulator" or simply "regulator" in this disclosure. The embodiment can be applied to the circuit designs of various linear-type or switching-type regulators. A low-dropout (LDO) regulator is used in FIG. **1** as an example.

As shown in FIG. **1**, the voltage regulating apparatus **100** may include a power transistor **110**, a feedback circuit **120**, an amplifier **130**, and a transient enhancement unit **140**. The power transistor **110** has three access terminals including a control terminal, a first terminal, and a second terminal, in which the first terminal is configured for receiving a power supply of voltage Vs for the voltage regulating apparatus **100**, and the second terminal can be used to be an output terminal of the voltage regulating apparatus **100** to provide an output voltage Vo. In other words, the voltage regulating apparatus **100** may generate its output voltage Vo at the second terminal of the power transistor **110**, so as to supply an electrical power of voltage Vo to an external circuit or device. Moreover, the power transistor **110** can be demonstrated by a metal-oxide-semiconductor field effect transistor (MOSFET). In the embodiment, the power transistor **110** is a p-channel MOSFET, with its gate acting as the control terminal as well as its source and drain acting as the first and second terminals.

To regulate the output voltage of the voltage regulating apparatus **100**, the feedback circuit **120** is connected to the second terminal of the power transistor **110** to receive the output voltage Vo. A fraction of the output voltage Vo is fed back to be an input signal of the amplifier **130** at the non-inverting input terminal. The feedback circuit **120** can be formed of a voltage divider, which consists of two resistors R_1 and R_2 in series. The fraction voltage Vd can be found at the connection point between the resistors R_1 and R_2 by the voltage division. The fraction voltage Vd is used as a feedback signal in the embodiment and the feedback circuit **120** can be implemented with another means other than the above voltage divider. It should be noticed that the voltage regulating apparatus **100** may include an environmental capacitor C, an equivalent series resistor R_{ESR}, and an equivalent load impedance (not shown) due to the supplied external devices at the output voltage Vo terminal, as shown in FIG. **1**.

The amplifier **130** amplifies the differential input signal between its non-inverting and inverting input terminals to drive the power transistor **110**. The non-inverting input terminal receives the feedback signal of fraction voltage Vd, the inverting input terminal receives a stable reference voltage V_{ramp}, and the output terminal is connected to the control terminal of the power transistor **110**. The amplifier **130** contains a source current unit with a source current I_P and a sink current unit with a sink current I_N. The output terminal of the amplifier **130** is connected to the control terminal of the power transistor **110** to drive the power transistor **110**, in which the output current is the current difference between the source current I_P and the sink current I_N. The source current I_P can be used to charge the power transistor **110**, so as to raise its gate voltage V_g; while the sink current I_N can be used to discharge the power transistor **110**, so as to lower the gate voltage V_g. In the embodiment, the source current unit is implemented with a p-type MOS transistor and the sink current unit is implemented with an n-type MOS transistor.

The transient enhancement unit **140** can monitor the source current I_P and the sink current I_N in the amplifier **130**, which are used to determine the operation state of the voltage regulating apparatus **100**. For example, the voltage regulating apparatus **100** may operate in a steady state (referred to as "first state") or in a transient state (referred to as "second state"). The transient enhancement unit **140** can regulate the gate voltage V_g of the power transistor **110** or either charge or discharge the gate of the power transistor **110** according to the monitored result.

In the embodiment, when the voltage regulating apparatus **100** is in a steady state, the output voltage Vo is stable or varies very slowly and the gate voltage V_g of the power transistor **110** is also stable or varies slowly. Thus, the source current I_P may be substantially equal to the sink current I_N, or the source current I_P is not different from the sink current I_N in a large extent. For example, the source current I_P is less than twice as much as the sink current I_N, or the sink current I_N is less than twice as much as the source current I_P. In such a circumstance, the amplifier **130** either does not charge or discharge the gate of the power transistor **110** or just charge or discharge the gate very slowly, to regulate the gate voltage V_g by means of the source current I_P and the sink current I_N.

On the other hand, when the output load of the voltage regulating apparatus **100** is switched from one load condition to another, the load current outputted by the voltage regulating apparatus **100** may change suddenly. The fast change may produce transient electrical spikes or pulses at the output voltage Vo. Due to the feedback configuration, the gate voltage V_g of the power transistor **110** is also affected by the fast change. Generally, a power transistor has a large surface area. If the gate voltage V_g varies too much, one of the source current I_P and the sink current I_N has to be much larger than the other one, so as to charge or discharge the gate of the power transistor **110**. For example, the source current I_P is more than twice as much as the sink current I_N, or the sink current I_N is more than twice as much as the source current I_P. In a conventional regulator without the transient enhancement unit **140**, it takes considerable time to charge or discharge the gate voltage V_g to a desired voltage value. To speed up the regulation at the gate voltage V_g, the source current I_P or the sink current I_N has to be large enough, but this will render the regulator to dissipate a large current in the steady state. In this embodiment, however, the transient enhancement unit **140** is designed to have a circuit configuration for monitoring the source current I_P and the sink current I_N in the amplifier **130**. For example, the transient enhancement unit **140** may operate in a switching hysteresis, which causes the gate voltage V_g of the power transistor **110** to increase or decrease in a short time by use of a much large current, when the voltage regulating apparatus **100** is in the transient state. Here the transient state can be the case that the source current I_P is larger than a value equal to a predetermined multiple (e.g., twice) of the sink current I_N, or the case that the sink current I_N is larger than a value equal to a predetermined multiple (e.g., twice) of the source current I_P. As a consequence, the power transistor **110** can be quickly driven to provide a sufficient current and a much stable voltage for an external load device.

The transient enhancement unit **140** may include a control unit **142** and a current source **145**. The control unit **142** is connected to the amplifier **130** and configured for comparing the source current I_P and the sink current I_N. If the source current I_P is larger than a value equal to a predetermined multiple of the sink current I_N, the control unit **142** may control the current source **145** to offer a current to the gate of the power transistor **110** to raise the gate voltage V_g. On the other aspect, if the sink current I_N is larger than a value equal to a predetermined multiple of the source current I_P, the control unit **142** may control the current source **145** to sink in a current from the gate of the power transistor **110** to lower the gate voltage V_g. In one embodiment, the control unit **142** can connect the current source **145** to the gate of the power transistor **110** when the sink current I_N is larger than twice as much as the source current I_P or when the source current I_P is larger than twice as much as the sink current I_N, so as to charge or discharge the gate of the power transistor **110** to respond to the load change. The current source **145** may have a current driving capacity larger than five times that of the source current I_P and the sink current I_N. But it is not limited thereto, the current driving capacity can be determined according to the regulator's practical requirements for stability and response time.

In the following paragraphs, the circuit operation of the voltage regulating apparatus **100** in FIG. **1** will be described in detail. In a first situation when the load current at the output terminal of the voltage regulating apparatus **100** is increased gradually, the output voltage Vo may decrease gradually, causing the fraction voltage Vd fed back to the non-inverting input terminal of the amplifier **130** to decrease gradually, too. The sink current I_N may be larger than the source current I_P, so that the gate voltage V_g of the power transistor **110** can be pulled down gradually and thus the output current of the power transistor **110** can rise gradually, to respond to the gradually increasing load current. In a second situation when the load current at the output terminal is increased sharply or swiftly due to a transient load change, the transient enhancement unit **140** may compare the source current I_P and the sink current I_N in a switching-hysteresis manner. If the sink current I_N is much larger than the source current I_P (for example, if the sink current I_N is larger than twice as much as the source current I_P in the embodiment), the transient enhancement unit **140** can provide the output current I_D of current source **145** to discharge the current energy at the gate of the power transistor **110**, to respond to the sharply or swiftly increasing load current. The discharging current I_D can pull down the gate voltage V_g of the power transistor **110**, so that the power transistor **110** can raise the output current at the output terminal of the voltage regulating apparatus **100**, to respond to the sharply or swiftly increasing load current. The above description, the regulator is based on the operation of up-tracking load current.

On the other hand, the regulator can be driven according to the operation of down-tracking load current. In a first situation when the load current at the output terminal of the voltage regulating apparatus **100** is decreased gradually, the output voltage Vo may increase gradually, causing the fraction voltage Vd fed back to the non-inverting input terminal of the amplifier **130** to increase gradually, too. The source current I_P may be larger than the sink current I_N, so that the gate voltage V_g of the power transistor **110** can be pulled up gradually and thus the output current of the power transistor **110** can be lowered gradually, to respond to the gradually decreasing load current. In a second situation when the load current at the output terminal is reduced sharply or swiftly due to a transient load change, the transient enhancement unit **140** may compare the source current I_P and the sink current I_N in a switching-hysteresis manner. If the source current I_P is much larger than the sink current I_N (for example, if the source current I_P is larger than twice as much as the sink current I_N in the embodiment), the transient enhancement unit **140** can provide the output current I_C of current source **145** to charge the gate of the power transistor **110**, to respond to the sharply or swiftly decreasing load current. The charging current I_C can pull up the gate voltage V_g of the power transistor **110**, so that the power transistor **110** can reduce the output current at the output terminal of the voltage regulating apparatus **100**, to respond to the sharply or swiftly decreasing load current.

FIG. **2** schematically shows a circuit diagram of a voltage regulating apparatus **200** according to another embodiment of the present disclosure, which is based on the circuit configuration in FIG. **1**. The transient enhancement unit **140** includes a first current source I_{PE} and a second current source I_{NE} configured for regulating the voltage V_g at the control terminal of the power transistor **110** according to the monitored result. The first current source I_{PE} and the second current source I_{NE} are arranged in a symmetrical circuit structure, similar to that of the source current I_P and the sink current I_N in the amplifier **130**. The transient enhancement unit **140** may further include a first switch **248** and a second switch **249**, connected to the first current source I_{PE} and the second current source I_{NE}, respectively. If the source current I_P is larger than a value equal to a predetermined multiple of the sink current I_N in the amplifier **130**, the control unit **142** may control the first current source I_{PE} to raise the gate voltage V_g. In the embodiment, the control unit **142** is implemented by use of a comparator, which can reproduce the source current I_P and the sink current I_N proportionally by means of a current mirror or the like, and compare them to generate a control signal to the operational state (ON or OFF) of the first switch **248** and the second switch **249**. The comparator may be of switching hysteresis to control the first switch **248** and the second switch **249**. For example, if the sink current I_N is larger than twice as much as the source current I_P, then the control unit **142** may control the second switch **249** to be turned on, so that the current of the second current source I_{NE} can be used to drive the power transistor **110**. If the source current I_P is larger than twice as much as the sink current I_N, then the control unit **142** may control the first switch **248** to be turned on, so that the current of the first current source I_{PE} can be used to drive the power transistor **110**. The other elements or components in the embodiment are the same as those in FIG. **1** and are not described redundantly.

FIG. **3** schematically shows a circuit configuration of the transient enhancement unit **140** as an example of the second embodiment, in which Vs is the power supply for the voltage regulating apparatus. The transient enhancement unit includes six p-channel MOSFETs and six n-channel MOSFETs. The gate of the p-channel MOSFET **330** receives a biased-voltage signal representing the source current I_P from the amplifier **130**, while the gate of the n-channel MOSFET **331** receives a biased-voltage signal representing the sink current I_N from the amplifier **130**. The p-channel MOSFET **330** and a n-channel MOSFET **341** are combined to be a current mirror delivering a current equal to the source current I_P, and the n-channel MOSFET **340** and a p-channel MOSFET **340** are combined to be another current mirror delivering a current equal to the sink current I_N. The control unit **142** or the comparator in the second embodiment can be implemented with the p-channel MOSFETs **330/340/380/390** and the n-channel MOSFETs **331/341/381/391**, which compare the source current I_P and the sink current I_N to produce a control signal to control the operational state (ON or OFF) of a p-channel MOSFET **370** and an n-channel MOSFET **371**.

As to the p-channel MOSFET **310**, the source is connected to the power supply of voltage Vs, the drain is connect the first switch **248**, and the gate is provided with a first predetermined voltage V_{BP}, so that the p-channel MOSFET **310** can deliver a constant drain current which acts as the first current source I_{PE} in the second embodiment. As to the n-channel MOSFET **311**, the source is grounded, the drain is connect the second switch **249**, and the gate is provided with a first predetermined voltage V_{BN}, so that the n-channel MOSFET **311** can deliver another constant drain current which acts as the second current source I_{NE} in the second embodiment. The p-channel MOSFET **370** may act as the first switch **248** in the second embodiment, wherein its gate is connected to the drain of the p-channel MOSFET **390**. The n-channel MOSFET **371** may act as the first switch **248** in the second embodiment, wherein its gate is connected to the drain of the n-channel MOSFET **391**. As a consequence, the control signal generated by the control unit **142** or the comparator can be received by the MOSFETs **370** and **371**.

In the embodiments, when the voltage regulating apparatus **200** operates in a steady state, the source current I_P may approximate to the sink current I_N; for example, in the extent that the source current I_P is less than twice as much as the sink current I_N or the sink current I_N is less than twice as much as the source current I_P. In such a circumstance, the p-channel MOSFET **370** (acting as the first switch) and the n-channel MOSFET **371** (acting as the second switch) are turned off, so that the transient enhancement unit **140** will not provide the power transistor **110** with the current for transient enhancement. On the other aspect, when the voltage regulating apparatus **200** operates in a transient state, the p-channel MOSFET **370** or the n-channel MOSFET **371** will be turned on. For example, if the source current I_P is less than twice as much as the sink current I_N in the amplifier **130**, the p-channel MOSFET **370** may be turned on and the n-channel MOSFET **371** may be turned off, so that the drain current of the p-channel MOSFET **310** (acting as the first current source I_{PE}) will charge the control terminal of the power transistor **110** to raise the gate voltage V_g, so as to enhance the transient response for a sudden load change. For another example, if the sink current I_N is less than twice as much as the source current I_P in the amplifier **130**, the n-channel MOSFET **371** may be turned on and the p-channel MOSFET **370** may be turned off, so that the drain current of the n-channel MOSFET **311** (acting as the second current source I_{NE}) will discharge the control terminal of the power transistor **110** to lower the gate voltage V_g, so as to enhance the transient response for a sudden load change. Here, the MOSFET **370** or **371** can have a current driving capacity larger than five times the source current I_P or the sink current I_N, but is not limit thereto.

As set forth in the embodiments, a transient enhancement unit is used in the present disclosure to speed up the response of a voltage regulating apparatus for transient load change, with a small quiescent-state current in a stable loading. Thus, no extra current will be dissipated in the steady state. With respect to the above description then, it is to be realized that the optimum dimensional relationships for the parts of the disclosure, to include variations in size, materials, shape, form, function and manner of operation, assembly and use, are deemed readily apparent and obvious to one skilled in the art, and all equivalent relationships to those illustrated in the drawings and described in the specification are intended to be encompassed by the present disclosure.

What is claimed is:

1. A voltage regulating apparatus, comprising:

a power transistor, having a control terminal, a first terminal for receiving a power supply, and a second terminal for providing an output voltage;

a feedback circuit, coupled to the second terminal, configured for providing a feedback voltage according to the output voltage;

an amplifier having a source current unit and a sink current unit, configured for driving the power transistor through the control terminal by use of the source and sink current units according to a reference voltage and the feedback voltage; and

a transient enhancement unit, configured for monitoring the source and sink current units, and regulating a voltage at the control terminal according to the monitored result.

2. The voltage regulating apparatus according to claim **1**, wherein the transient enhancement unit comprises:

a control unit, comprising a comparator, configured for comparing a source current of the source current unit and a sink current of the sink current unit to produce the monitored result; and

a current source, comprising a first current unit and a second current unit, configured for regulating the voltage at the control terminal according to the monitored result.

3. The voltage regulating apparatus according to claim **2**, wherein the control unit increases the voltage at the control terminal by use of the first current unit when the source current is larger than a value equal to a predetermined multiple of the sink current.

4. The voltage regulating apparatus according to claim **2**, wherein the control unit decreases the voltage at the control terminal by use of the second current unit when the sink current is larger than a value equal to a predetermined multiple of the source current.

5. The voltage regulating apparatus according to claim **2**, wherein the comparator has a switching hysteresis, which causes the control unit to control the first current unit to offer a current to the control terminal when the source current is larger than twice as much as the sink current, so as to raise the voltage at the control terminal.

6. The voltage regulating apparatus according to claim **2**, wherein the comparator has a switching hysteresis, which causes the control unit to control the second current unit to let a current sink in from the control terminal when the sink current is larger than twice as much as the source current, so as to lower the voltage at the control terminal.

7. The voltage regulating apparatus according to claim **2**, wherein the first current unit has a current driving capacity larger than five times that of the second current unit.

8. The voltage regulating apparatus according to claim **2**, wherein the second current unit has a current driving capacity larger than five times that of the first current unit.

9. A voltage regulating apparatus, comprising:

a power transistor, having a control terminal, a first terminal for receiving a power supply, and a second terminal for providing an output voltage;

a feedback circuit, configured for providing a feedback voltage according to the output voltage;

an amplifier having a source current unit and a sink current unit, configured for receiving a reference voltage and the feedback voltage, and driving the power transistor through the control terminal by use of the source and sink current units; and

a transient enhancement unit, configured for monitoring the source and sink current units, and charging or discharging the control terminal according to the monitored result.

10. The voltage regulating apparatus according to claim **9**, wherein the transient enhancement unit comprises:

a control unit, configured for comparing a source current of the source current unit and a sink current of the sink current unit to produce the monitored result.

11. The voltage regulating apparatus according to claim **10**, wherein the transient enhancement unit further comprises:

a current source, configured for offering a current to the control terminal when the source current is larger than a value equal to a predetermined multiple of the sink current.

12. The voltage regulating apparatus according to claim **10**, wherein the transient enhancement unit further comprises:

a current source, configured for receiving a current from the control terminal when the sink current is larger than a value equal to a predetermined multiple of the source current.

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